IV. *On the Automatic Registration of Magnetometers, and Meteorological Instruments, by Photography.—No. III.* *By* Charles Brooke, *M.B., F.R.S.*

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On the Construction of the Self-registering Thermometer Apparatus.

In my second paper on Automatic Registration*, the means of obtaining a photographic register of the variations of the thermometer were briefly mentioned, and in the annexed plate a specimen was given of the register thus obtained; but as an apparatus possessing the requisites for practical application had not then been constructed, it may not be undesirable to those who are interested in the advancement of meteorological science, to know the means by which this object has been accomplished. A vertical revolving cylinder, and the carrying time-piece described in the above paper (see Plate VI. figs. 4, 5, 6, 7, 8), are mounted on a stand measuring 30 inches by 12, supported by four legs; the stems of the thermometer and psychrometer pass up through the table, and between the lenses and the adjacent surfaces of the cylinder; and the long cylindrical bulbs are sufficiently below the stand to be freely influenced by the currents of air, and at the same time to remain wholly unaffected by the heat of the lamps which are placed on wooden supports at each end of the stand, at such a height that the flame may be opposite the middle of the photographic paper on the cylinder.

As it is impossible to superpose two registers of these instruments on the same paper, which may be done without inconvenience when the indication consists in a dark line, as in the photographs of the barometer and the magnetometers, the time-piece is so constructed that the hour-hand makes half a revolution in twenty-four hours. By this arrangement the two halves of the paper surrounding the cylinder give respectively a perfect diary of the two instruments. The glass cylinder is covered by a concentric cylindrical zinc case, having slits on opposite sides corresponding to the stems of the instruments, which are capable of being closed by sliding doors; by these means the cylinder, protected by its case, may be carried to or from the room in which the photographic manipulations are conducted, without any risk of exposure to light. The whole apparatus is also covered by a wind- and water-tight zinc case which rests on the stand, and is divided into separate compartments for the lamps by a partition towards each end, for the purpose of more completely isolating the thermometers from the heat produced by their combustion.

The cylindrical arrangement above described, so obviously desirable in enabling

* See Philosophical Transactions, 1847, Part I.

the two thermometric instruments to be registered by one apparatus and on one piece of paper, was at first open to a grave objection, which has however subsequently been entirely removed. The pencil of rays incident on the stem of the thermometer must necessarily be a fan-shaped pencil, by the oblique rays of which the points corresponding to each degree would not be transferred to the respectively opposite points of the paper. If the surface of the cylinder were always parallel to, and equidistant from, the stem of the thermometer, this distortion of the scale would be constant and uniform, and therefore readily estimated; but from the unavoidable imperfections in form and variations in size of the different cylinders employed, it would be extremely difficult to estimate correctly the distortion of the scale, and hence to infer the true temperature from the register. And this uncertainty would have been especially felt at very low temperatures, when the place of the mercury is impressed by the most oblique rays on the paper, and when small errors of relative temperature would largely affect the deduced hygrometric condition of the atmosphere. This difficulty has been obviated by enabling the apparatus to print continuously the scale of the thermometers, as well as to indicate the position of the mercury. This has been effected by placing fine wires, opposite to each degree, across the aperture in the scale frame, through which the light is transmitted to the stem of the instrument. By these wires a minute portion of the exposed paper is protected from light, and thus the darkened portion of the register is traversed by a series of parallel lines, corresponding with the scale of the thermometer. In order to remove any ambiguity in the reading of this scale, a coarser wire is placed at every ten degrees, and an additional coarse wire at the points 32°, 54°, 76° and 98°; as one of these points may always be made to appear on the register, the relative position of the extra coarse wire will determine the point of the scale which it represents.

It may here be mentioned that the wet bulb, although more than 6 inches in length, is kept perfectly saturated by being moistened at three different points by small bundles of lamp-cotton placed round the muslin covering of the bulb, and immersed in a vessel of water placed nearly opposite its middle point.

It is very evident that the apparatus must afford some ready method of marking the time-scale on the paper, that is, of identifying any given epoch of time with the indications of the register: this is effected by closing at any two known times the sliding doors of the cylindrical case, for five minutes, and then re-opening them. Two undarkened lines will be observed on the paper, corresponding to the known times; the intervening space being subdivided by the elastic scale, the time-scale is rendered complete*.

It may also be remarked, that in all the other photographic registers obtained at the Royal Observatory by the instruments previously described, the only certain method of marking the time-scale is found to consist in breaking the continuity of the line at a known epoch: this is effected by a piece of brass similar to one side of a

* As a facsimile of a photographic diurnal register will be found in the Greenwich Magnetical and Meteorological Observations for 1837, it is unnecessary to introduce it in this place.

parallel ruler, placed edgewise, one of the connecting pieces being prolonged and passing down through the stand to act as a lever, by which the parallel moving piece is raised between the cylindrical lens and the cone of the cylinder, so as to intercept the pencil of light which traces the register line. The light is usually excluded for 5^m, admitted for 1^m, again excluded for 5^m, and then re-admitted, the times of exclusion, admission and re-admission being recorded. If, during the second passage of the tracing pencil of light over the paper, a break of six or eight minutes be made, without the intervening spot, it will be found a convenient method of distinguishing the two lines, in case of any ambiguity.

The scales of the thermometers in use have about 8° to 1 inch, from the registers of which the temperature may be readily read with certainty to less than a tenth of a degree. Of this scale, a space of about 60° may be illuminated at one time; and in order that the temperature indicated may always be within the field, the thermometers are capable of being raised or lowered by a screw, so as to bring the mean temperature of the season nearly opposite the middle of the paper: thus there is no probability that the record of any unusual and extreme changes of temperature will be lost.

In the description of the camphine lamp given in the first paper, previously referred to, the wick was stated to have been placed below the diaphragm in the chimney; it has since been found that there is another position in which equally perfect combustion takes place, which is when the wick is raised to about an equal distance above the diaphragm; with this position of the wick, the liability to smoke is very materially diminished.

Equally good effects have recently been produced by gas, saturated with the vapour of coal naphtha, which renders the light much whiter and more intense. Without this addition to the gas the photographic paper is feebly affected during periods of rapid movement of the magnet. The light used is that of a small fish-tail burner, so made as to spread the gas as much as possible; the flame is placed edgewise towards the mirror, in which position the illumination of the mirror is the brightest.

The employment of these instruments is not however limited to localities in which either camphine or gas is accessible; for the barometer and thermometers, in which large and rapid movements of the tracing pencil of light are never required to be depicted, an oil-lamp will answer sufficiently well: and by the same means the ordinary diurnal variations of the magnetometers may be delineated; but no opportunity has yet occurred of obtaining, by means of an oil-lamp, a register of the rapid movements occurring during a considerable disturbance.

On a New Method of determining the Scale and Temperature Coefficients of Magnets used in observing the Changes of Magnetic Force.

It appears from the ordinary formula expressing the equilibrium of the bifilar magnet, that small changes in the amount of horizontal force will have the same effect in displacing the magnet, as small corresponding changes in the suspended weight. Having then carefully weighed the magnet, the mirror and the suspending frame, two

small weights have been made, each equal to the $\frac{1}{1000}$th part of the whole weight. While the register is in action, one of these weights is placed on the torsion circle, and at an interval of time equal to that of one oscillation of the magnet, the second is added: if this be carefully done, the magnet will be very nearly at rest in its new position. After half an hour, or any convenient interval of time, the weights are removed in the same manner; and this must be repeated sufficiently often to eliminate the error of reading by a finely divided scale the displacement of the register line. Half the scale reading of this displacement may therefore be taken as the value of 0·001 of the whole horizontal force. By this process the necessity of making several accurate linear measurements of the apparatus, and the errors that might arise therefrom, are avoided.

The following is the proposed method of determining the temperature coefficient. Let two magnets, one of them having a known coefficient, and that of the other to be now determined, be suspended in the bifilar method, at a distance of 15 feet from each other, the line joining their centres being a normal to the plane of the magnetic meridian. The torsion of the double threads should be in opposite directions, so that when the magnets are duly adjusted in equilibrium, in the line joining their centres, the similar poles may be towards each other.

The most convenient scale coefficient of the bifilar magnet, for the purpose of photographic registration, appears to be that which renders the angular value of the ordinary diurnal range nearly equal to the range of the declination magnet; the pulley over which the suspension thread of what may be called the standard magnet passes, being made of such a size as to give the required value to its scale coefficient, the distance between the threads of the other or trial magnet may be conveniently adjusted by a right- and left-handed screw (as in the suspension frame described in a former paper), so as to give a nearly equal value to its scale coefficient. The previously described arrangements for photographic registration being made, the registering apparatus is placed midway between the magnets, and by a few trials, the ratio of its distances from the magnets may be so arranged as to make their scale coefficients exactly equal. The magnets, having been previously protected by a coat of varnish, are suspended in water. The vessel made use of is a double zinc trough or box, the inner one being 18 inches long, 2 inches wide, and 4 inches deep, the outer one 3 inches longer and wider, leaving an equal space on all sides between the two, and half an inch deeper, with separate covers to each. For the standard magnet, the inner box only should be filled with water, the intervening space of air between the two tending to retard any variation of temperature of the water. For raising the temperature of the trial magnet, the outer box should be filled with warm water at such a temperature as will raise the water in the inner box to about 100° Fahr. For lowering it to 32° Fahr., the outer box, or rather the space between the two, should be filled with a freezing mixture. The whole being allowed to cool gradually in the one case, and in the other to be raised gradually to the temperature of the atmosphere, the change of temperature will be found to be so slow, that the

temperature of the magnet may be presumed identical with that of the water in which it is immersed. This is ascertained by a thermometer with a long cylindrical bulb reaching nearly from the top to the bottom of the vessel, by which means it is presumed that the average temperature of the water will be most nearly determined.

These arrangements having been made, a simultaneous register of the two magnets is obtained, during the progress of which, the temperature of the magnets must be observed at recorded times, and at any convenient intervals of from a quarter of an hour to two or three hours, the intervals of observation being least at the highest and lowest temperatures of the trial magnet, when the change is most rapid. Having marked upon the register the epochs of observation, the differences between the changes of position of the lines at these points may be measured by a scale, and these differences will very accurately represent the scale-value of the changes of force due to the corresponding changes of temperature of the trial magnet; for ordinarily the temperature of the standard magnet may be considered constant during each of the intervals of observation.

A sufficient number of these differential scale-readings having been obtained, they may for reduction be conveniently arranged in five groups, between the temperatures 32°, 45°, 60°, 75°, 90°, 100°. Denoting the differences of temperature by D, the mean temperatures of the periods of observation by M, and the scale-readings by R, the mean temperature of each group is found from the formula $\frac{\Sigma(\mathrm{M}\times\mathrm{D})}{\Sigma(\mathrm{D})}$, and the corresponding mean value of R for an interval of 1° Fahr. from the formula $\frac{\Sigma(\mathrm{D}\times\mathrm{R})}{\Sigma(\mathrm{D}^2)}$, which may be represented by $\Delta\mathrm{K}$, K being the temperature coefficient. As it has been found convenient to reduce magnetic observations to the temperature of 32° Fahr., let the excess of the above mean temperatures above that point be represented by t, and let x and y be the coefficients of the first and second powers of t in the value of K; then five equations will be obtained of the form

$$\Delta\mathrm{K}=x+yt,$$

which being solved by the method of least squares, will give probably correct values of x and y. From the form of the preceding equation, it follows that

$$\mathrm{K}=xt+\frac{1}{2}yt^2.$$

The above method has been applied to determine the temperature coefficients of two bar-magnets marked C.B. VIII. and C.B. IX*. But as the premises on which the observations were made present the usual obstacles of a dwelling-house to the free action of magnetic instruments, namely, the large mass of iron contained in the grates, only one position could be found in which the effects of the most contiguous masses of iron would nearly neutralize each other: and in consequence of this difficulty, the register of the trial-magnet here obtained has been compared with that obtained

* These magnets belong to a complete set of self-registering photographic apparatus intended to be presented to the Observatory at Cambridge by the Master of Trinity College.

simultaneously at the Royal Observatory; the result is therefore open to the objection of a *possible* difference in the changes of horizontal force at the two places. But it appears from a comparison of several photographic registers obtained simultaneously at Greenwich and in Keppel Street, some of which include periods of considerable disturbance, that a difference in the simultaneous changes of horizontal force in these two localities is very rarely perceptible.

The annexed Table contains the numerical observations from which the temperature coefficient of the bar C.B. VIII. has been determined. The scale-readings are taken

C.B. VIII.

Times of observation. March, 1849.	Scale-readings of Royal Observatory registers.	Differences.	Corresponding values on my scale. A×1·115.	Differences of my scale-readings.	Scale-readings of my registers.	Temperatures. Fahr.	Differences of temperature.	Mean temperatures.	Reduced scale-readings. B+C.	D^2.	D×R.	D×M.
d h m		A.	B.	C.			D.	M.	R.			
0 22 5	627				55	100·5						
30	630	3	3	80	135	95·2	5·3	97·9	83	2809	4399	51887
23 0	630	0	0	74	209	90·5	4·7	92·8	74	2209	3478	43616
30	628	− 2	− 2	54	263	87·3	3·2	88·9	52	1024	1664	28448
1 0 0	630	2	2	42	305	84·2	3·1	85·8	44	961	1364	26598
30	626	− 4	− 5	49	354	81·2	3·0	82·7	44	900	1320	24810
1 0	610	−16	−18	51	405	78·8	2·4	80·0	33	576	792	19200
2 4	610	0	0	89	494	73·4	5·4	76·1	89	2916	4806	41094
22 0	635				30	92·8						
30	639	4	5	78	108	88·4	4·4	90·6	83	1936	3652	39864
23 0	644	5	6	58	166	85·5	2·9	86·9	63	841	1827	25201
30	668	24	28	14	180	83·3	2·2	84·4	42	484	924	18568
2 0 0	660	− 8	− 9	58	238	80·4	2·9	81·8	49	841	1421	23722
1 0	652	− 8	− 9	83	321	75·8	4·6	78·1	74	2116	3404	35926
2 0	653	1	1	53	374	72·1	3·7	74·0	55	1369	2035	27380
3 0	646	− 7	− 8	54	428	68·9	3·2	70·5	46	1024	1472	22560
4 0	646	0	0	24	452	67·2	1·7	68·0	24	289	408	11560
5 10	621	−25	−29	57	509	65·3	1·9	66·2	28	361	532	12578
7 0	617	− 4	− 5	42	551	62·6	2·7	64·0	37	729	999	17280
11 38	608	− 9	−10	44	595	60·0	2·6	61·3	34	676	884	15938
20 19	601+16	9	10	21	616	58·0	2·0	59·0	31	400	620	11800
8 21 8	563				18	103·0						
34	572	9	10	74	92	98·5	4·5	100·8	84	2025	3780	45360
22 8	574	2	2	90	182	93·2	5·3	95·9	92	2809	4876	50827
48	596	22	25	58	240	88·5	4·7	90·8	83	2209	3901	42676
23 38	584	−12	−14	95	335	83·9	4·6	86·2	81	2116	3726	39652
9 0 3	556	−28	−32	63	398	81·8	2·1	82·8	31	441	651	17388
1 0	582	26	30	40	438	77·4	4·4	79·6	70	1936	3080	35024
2 25	562	−20	−23	103	541	72·6	4·8	75·0	80	2304	3840	36000
3 0	547	−15	−17	51	592	70·7	1·9	71·7	34	361	646	13623
30	560	13	15	16	608	69·4	1·3	70·1	31	169	403	9113
4 0	569	9	10	19	627	68·2	1·2	68·8	29	144	348	8256
5 7	573	4	4	30	657	66·7	1·5	67·5	34	225	510	10125
6 0	573	0	0	38	695	65·0	1·7	65·9	38	289	646	11203
40	576	3	3	24	719	63·7	1·3	64·4	27	169	351	8372
7 57	565	−11	−13	51	770	62·1	1·6	62·9	38	256	608	10064
9 9	568	3	3	15	785	60·8	1·3	61·4	18	169	234	7982
10 44	557+ 2	− 9	−10	22	807	59·6	1·2	66·2	12	144	144	7224
21 15	580+12	33	38	23	830	55·2	4·4	57·4	61	1936	2684	25256

C.B. VIII. (Continued.)

Times of observation. March, 1849.	Scale-readings of Royal Observatory registers.	Differences.	Corresponding values on my scale. A×1·115.	Differences of my scale-readings.	Scale-readings of my registers.	Temperatures. Fahr.	Differences of temperature.	Mean temperatures.	Reduced scale-readings. B+C.	D².	D×R.	D×M.
d h m		A.	B.	C.			D.	M.	R.			
10 1 42	600				195	33·5						
2 0	597	3	3	5	190	34·1	0·6	33·8	8	36	48	2028
2 30	589	8	9	6	184	35·2	1·1	34·6	15	121	165	3806
3 0	572	17	20	−1	185	36·8	1·6	36·0	19	256	304	5760
30	569	3	3	18	167	38·7	1·9	37·7	21	361	399	7163
4 0	569	0	0	20	147	40·4	1·7	39·5	20	289	340	6715
43	565	4	5	13	134	41·7	1·3	41·1	18	169	234	5343
5 38	567	− 2	− 2	22	112	42·8	1·1	42·3	20	121	220	4653
6 0	565	2	2	9	103	43·4	0·6	43·1	11	36	66	2586
7 13	557	8	9	13	90	44·8	1·4	44·1	22	196	308	6174
8 13	562	− 5	− 6	27	63	46·1	1·3	45·5	21	169	273	5915
9 9	571	− 9	−10	28	35	47·0	0·9	46·6	18	81	162	4194
43	565	6	7	1	34	47·5	0·5	47·3	8	25	40	2365
11 28	565	0	0	19	15	48·7	1·2	48·2	19	144	228	5784
11 6 40	550				92	69·8						
7 30	549	− 1	− 1	36	128	67·5	2·3	68·6	35	529	805	15678
8 8	551	2	2	19	147	65·8	1·7	66·7	21	289	357	11339
9 7	547	− 4	− 5	31	178	63·8	2·0	64·8	26	400	520	12960
10 21	547	0	0	29	207	61·7	2·1	62·7	29	441	601	13167
59	547	0	0	12	219	60·8	0·9	61·2	12	81	108	5508
11 23 45	614				654	33·2						
58	612	2	2	9	645	33·9	0·7	33·6	11	49	77	2352
12 0 20	608	4	5	14	631	35·4	1·5	34·6	19	225	285	5190
45	606	2	2	17	614	36·8	1·4	36·1	19	196	266	5084
1 0	596	10	11	3	611	37·8	1·0	37·3	14	100	140	3730
48	579	17	20	17	594	40·7	2·9	39·2	37	841	1073	11368
2 18	569	10	11	8	586	42·0	1·3	41·4	19	169	247	5382
3 0	579	−10	−11	33	553	43·5	1·5	42·8	22	225	330	6420
4 0	566	13	15	13	540	45·4	1·9	44·4	28	361	532	8436

on a scale having 100 divisions in an inch. The differences of the scale-readings of the Royal Observatory registers are reduced to the scale of the observed magnet by multiplying them by the ratio of the scale coefficients: this ratio is expressed by 1·115*. The reduced scale-readings, R, are the sums of the readings B and C, because the variation is represented in opposite directions on the two registers.

These quantities being arranged in five groups according to the temperatures M, and the mean values obtained by the above formulæ, the five following equations result:—

$$\begin{array}{ll} x+\ 7{\cdot}2y=13{\cdot}42 & \\ x+21{\cdot}7y=14{\cdot}54 & \\ x+34{\cdot}6y=15{\cdot}55 & \text{residual errors} \\ x+49{\cdot}5y=16{\cdot}50 & \\ x+62{\cdot}8y=17{\cdot}20 & \end{array} \left\{\begin{array}{l} -0{\cdot}10 \\ +0{\cdot}02 \\ +0{\cdot}15 \\ +0{\cdot}08 \\ -0{\cdot}12 \end{array}\right.$$

* In the very few instances in which it appeared necessary, a correction has been applied to the Greenwich scale-readings for observed changes of temperature.

These equations, solved by the method of least squares, give

$$x=13\cdot0269\,; \qquad y=0\cdot0685.$$

By the method of weights described above, the scale value of 0·001 of the total horizontal force was found to be 25·27 sc. div., consequently the values of x and y expressed in parts of force are

$$x=0\cdot00051550\,; \qquad y=0\cdot000002710.$$

As the effect of a small increase of weight in displacing the magnet is the same as that of a small corresponding diminution of force, when the correction is subsequently applied to the magnet suspended in air, the value of x above found must be diminished by a small quantity representing the effect of the increase of weight due to the weight of the water displaced by the magnet being diminished by expansion, as the temperature increases; this may be called the coefficient of expansion, and may be thus found.

Let w, s, b be the cubical expansions of water, steel and brass respectively, for 1° FAHR., then

$$w=0\cdot0001500 \text{ (URE)}$$
$$s=0\cdot0000204 \text{ (SMEATON)}$$
$$b=0\cdot0000291\,;$$

and if U be the weight lost by the magnet at 32° FAHR., and U′ the weight lost at any observed temperature, $32°+t°$, the value of U will be

$$U'\{1+(w-s)t\}=U'(1+0\cdot0001296\,t)\,;$$

and if V and V′ similarly represent the weights lost by the stirrup and end of the frame immersed,

$$V=V'\{1+(w-b)t\}=V'(1+0\cdot0001209\,t).$$

Let W be the weight in air of the magnet and its appendages, then the coefficient of expansion for $t°$ above 32° expressed in parts of the force will be

$$\frac{U\times0\cdot0001296+V\times0\cdot0001209}{W}\,t.$$

In the present instance the value of this coefficient is

$$0\cdot00001022\,t, \text{ or } 0\cdot00001t \text{ nearly,}$$

and the value of x being diminished by this quantity, the whole temperature coefficient will be

$$0\cdot00050528\,t+0\cdot000001355t^2.$$

The temperature coefficient of the bar (C.B. IX.) similarly determined is

$$0\cdot0003822\,t+0\cdot000000947t^2.$$

In both these instances, it will be seen that the temperature coefficient varies considerably from the uniform law usually employed in the reduction of magnetic ob-

servations*; and as it is impossible to foresee what points of scientific interest in the investigation of magnetic changes may depend on the determination of small quantities, and on the relation of magnetic variation in warm and cold climates, it may be considered not undesirable to ascertain, with the greatest attainable degree of accuracy, the temperature coefficients of all magnets to be employed in observing the changes of force. In the method here proposed, the magnet is under circumstances precisely similar to those which would exist when it is subsequently used in observation; it may therefore be considered less open to objection than the ordinary method of deflection, by which the temperature coefficient is inferred from the mutual action of two magnets and the earth on each other. Amongst other sources of uncertainty in the latter method, may be mentioned the unexplained difference in the result that has frequently been observed, according as the marked or unmarked pole of the deflecting, has been turned towards the deflected magnet; arising probably from the unequal, and possibly variable, distribution of magnetism throughout the bar; which conditions, if they really exist, will have precisely the same effect on the indications of the magnet when under trial, as they would have when it is in actual use.

By introducing the differences only of the scale-readings into the calculation, large numerical quantities are avoided, as well as the necessity of adopting a zero point, or scale-reading corresponding to no deflecting force.

* The fact of the decrease of magnetic intensity not being in the simple ratio of the increase of temperature, but in some higher ratio, was it is believed first announced by Professor Christie, Sec. R.S., in the Philosophical Transactions, 1825, p. 63.

Keppel Street, 1849, *June* 21.